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## Clinical evaluation of Keeler Pulsair 3000 non-contact tonometer

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## Clinical evaluation of Keeler Pulsair 3000 non-contact tonometer

### Abstract

**Background:** The Keeler Pulsair 3000 is a recently introduced non-contact tonometer that is especially useful for children and those for whom sitting at a slit lamp or table-mounted unit would be difficult. In this project, intra-ocular pressures (IOPs) measured by Keeler 3000 and Goldmann tonometers were compared to assess validity and reliability of the Keeler data.

**Methods:** Two Keeler IOPs (each the mean of four individual air-puff readings) and two Goldmann IOPs were measured for each eye of 113 subjects. Subjects were also asked which measurement technique they preferred.

**Results:** IOP ranged from 9 to 28 mm Hg. Correlations between the two Goldmann IOPs measured for the right and left eyes were 0.98 and 0.97 respectively. These values are higher than correlations between Keeler and Goldmann measurements (0.86 to 0.91). Keeler IOPs were slightly above Goldmann values for pressures of less than 15 mm Hg and slightly below for IOPs over 15 mm Hg. Extrapolation to a Goldmann IOP of 30 mm Hg suggests that the Keeler would read about 6% (1.7 mm Hg) too low at this IOP. Eight eyes (7%) had differences between Keeler and Goldmann IOP readings of 5.0 mm Hg or more. For three eyes, single outlier pressures readings produced by the Keeler caused these differences.

**Conclusions:** In the range of 10 to 24 mm Hg, the Keeler tonometer produced IOPs that corresponded well with Goldmann values for most eyes and was preferred by the majority of subjects who indicated a preference. The Pulsair 3000 is relatively easy to use by technicians and has numerous special applications in optometric practice.

### Degree Type

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### Degree Name

Master of Science in Vision Science

### Committee Chair

Robert L. Yolton

### Keywords

tonometry, keeler, pulsair, pulsair 3000, goldmann, glaucoma

### Subject Categories

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**CLINICAL EVALUATION OF THE  
KEELER PULSAIR 3000  
NON-CONTACT TONOMETER**

By

Wendy Lawson-Kopp  
Amy DeJong

A thesis submitted to the faculty of the

College of Optometry  
Pacific University  
Forest Grove OR 97116

For the degree of  
Doctor of Optometry  
May 2001

Advisor:  
Robert L. Yolton, PhD, OD

**CLINICAL EVALUATION OF THE  
KEELER PULSAIR 3000  
NON-CONTACT TONOMETER**

Advisor:

A handwritten signature in blue ink, appearing to read "Robert L. Yolton". The signature is fluid and cursive, with the first name "Robert" and last name "Yolton" clearly distinguishable.

Robert L. Yolton PhD, OD

## **Biographies**

Wendy Lawson-Kopp will complete her Doctor of Optometry degree in May of 2001. She previously attended North Dakota State University and received her Bachelor of Science in Visual Science from Pacific University. After graduation, she plans to return to the Midwest and practice in either Minnesota or North Dakota.

Amy DeJong will complete her Doctor of Optometry degree in May 2001. She previously attended the University of South Dakota, where she received her Bachelor of Science in Psychology with a minor in Biology. After graduation, she plans to return to the Midwest and practice in Iowa and South Dakota.

## **Abstract**

Background: The Keeler Pulsair 3000 is a recently introduced non-contact tonometer that is especially useful for children and those for whom sitting at a slit lamp or table-mounted unit would be difficult. In this project, intra-ocular pressures (IOPs) measured by Keeler 3000 and Goldmann tonometers were compared to assess validity and reliability of the Keeler data.

Methods: Two Keeler IOPs (each the mean of four individual air-puff readings) and two Goldmann IOPs were measured for each eye of 113 subjects. Subjects were also asked which measurement technique they preferred.

Results: IOP ranged from 9 to 28 mm Hg. Correlations between the two Goldmann IOPs measured for the right and left eyes were 0.98 and 0.97 respectively. These values are higher than correlations between Keeler and Goldmann measurements (0.86 to 0.91). Keeler IOPs were slightly above Goldmann values for pressures of less than 15mm Hg and slightly below for IOPs over 15 mm Hg. Extrapolation to a Goldmann IOP of 30 mm Hg suggests that the Keeler would read about 6% (1.7 mm Hg) too low at this IOP. Eight eyes (7%) had differences between Keeler and Goldmann IOP readings of 5.0 mm Hg or more. For three eyes, single outlier pressures readings produced by the Keeler caused these differences.

Conclusions: In the range of 10 to 24 mm Hg, the Keeler tonometer produced IOPs that corresponded well with Goldmann values for most eyes and was preferred by the majority of subjects who indicated a preference. The Pulsair 3000 is relatively easy to use by technicians and has numerous special applications in optometric practice.

Key Words: Tonometry, Keeler, Pulsair, Pulsair 3000, Goldmann, glaucoma, intra-ocular pressure, IOP, vision, optometry



## **Introduction**

The Keeler Pulsair 3000 is the most recent evolution of the Pulsair non-contact tonometer series.<sup>1,2,a</sup> Introduced in 1998, the 3000 retains the hand-held capabilities of earlier models but has several added features including improved accuracy, a better alignment and triggering system, and a lower pressure air-puff. The Pulsair 3000 also has a "bad event" detection system that warns if the lid or a lash has interfered with an intra-ocular pressure (IOP) measurement.<sup>b</sup>

As opposed to measurements made with a slit lamp-mounted Goldmann tonometer,<sup>3,4</sup> hand-held, non-contact tonometry is particularly advantageous for use with children and patients who cannot sit at a slit lamp. In addition, the Pulsair 3000 is portable enough to be moved from office to office and can be used with the patient in any position, e.g., reclining.

Although these factors are important, perhaps the greatest advantage of Keeler non-contact tonometry is that it can be performed without anesthetic, corneal contact, or probe disinfection by technicians following a training period of only an hour or two.<sup>b</sup> To illustrate the brief learning period, the instruction portion of the Pulsair 3000 manual is only seven pages long.<sup>5</sup> (Keeler also supplies an instructional summary on a single laminated sheet.)

### **Features and Specifications**

The Pulsair 3000 consists of a tabletop (or wall-mountable) console unit containing an air compressor and a hand piece containing the recording and IOP display systems. These units are connected by a

flexible umbilical cord. (Specifications for the Pulsair 3000 are shown in Table 1)

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Insert Table 1 About Here

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#### Measuring IOPs with the Pulsair 3000

When the hand-piece is removed from the console, the air compressor automatically starts. A system check for proper function can be performed by pressing the hand-piece 'Demo' button twice resulting in IOP readings of 30 and 50 mm Hg. No other calibration is required by the user.

To measure an IOP, the 'New Eye' and 'Set/Reset' buttons are pressed in sequence. The patient's eye is then viewed through the eyepiece with the objective lens approximately 15 mm from the cornea, and two D-shaped images are focused by moving the hand-piece. (Figure 1) When the proper alignment is obtained, the unit automatically produces a brief puff of air. This puff increases in pressure until infrared optics in the hand-piece detect a requisite degree of corneal applanation. The Imbert-Fick Law is then used to relate the intensity of the puff to the eye's IOP.<sup>3,4</sup>

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Insert Figure 1 About Here

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Four individual air-puffs are presented to obtain four separate IOP readings that are averaged by the Pulsair to produce a measurement of the eye's IOP. Although the Pulsair 3000 automatically displays the

average IOP measurement, individual IOP readings can be displayed by pressing the 'Review' button on the hand-piece. (Unless otherwise specified, the terms "Keeler IOP" and "Keeler measurement" refer to the mean of four individual IOP readings.)

Four readings are averaged, in part, because non-contact tonometers make their measurements very quickly. For this reason, individual Pulsair readings are subject to transient pulse or respiration pressure variations and to movements by the subject. Keeler has concluded that averaging four individual readings removes the effects of these variables.

In its primary operating mode, the Pulsair 3000 produces an air-puff capable of measuring IOPs between 7.0 and 30.0 mm Hg. The upper limit keeps the puff pressure low and makes it more comfortable for the patient. If pressures of over 30.0 mm Hg are detected, the unit automatically switches to the 'Airpulse+' mode and produces stronger puffs capable of measuring IOPs up to 50.0 mm Hg. When the Airpulse+ mode is engaged, an LED on the hand-piece is illuminated.

The Pulsair 3000 monitors individual IOPs as they are obtained, and, if a "bad-event" caused by lash or lid interference, an eye movement, or a blink is detected, 'Er' is displayed and the unit switches to the Airpulse+ mode. The IOP display on the hand-piece also flashes indicating that four valid IOP readings were not recorded because a bad-event occurred.

In addition, the Pulsair 3000 has a "Subflux" option that makes it easier for the unit to trigger with dry, scarred, or highly astigmatic corneas.

## Project Goals

The goals of this project were to compare IOPs measured with Pulsair 3000 and Goldmann tonometers using a population of subjects with normal and elevated IOPs and to assess the subjects' preferences for Pulsair or Goldmann measurement methods.

## **Subjects and Methods**

### Subjects

IOPs were measured from 226 eyes of 113 adults. Each subject gave informed consent and was paid \$10 for participation in the project. Characteristics of the subjects are shown in Table 2.

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Insert Table 2 About Here  
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A special effort was made to locate subjects with IOPs over 20 mm Hg. As a result, the distribution of IOPs from individual eyes shown on Figure 2 does not represent the typical distribution of IOPs in a normal population.

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Insert Figure 2 About Here  
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### Methods

All IOP measurements were made by an optometrist with 5 years of clinical experience. Prior to this project, he had made over 1,000 Goldmann IOP measurements, over 500 measurements with the Keeler Pulsair 2000 (an earlier version of the 3000), and over 100 measurements with the Pulsair 3000.

The Keeler Pulsair 3000 tonometer and a Nikon Goldmann tonometer (mounted on a Zeiss slit lamp) used in this study were furnished as new units by Keeler with assurances that the Pulsair was a representative, production-run unit and was not specially modified or adjusted for this study.<sup>b</sup> Calibration of both units was checked daily; no problems were encountered with either tonometer during the study.

#### Measurement Procedures

IOPs were measured for each eye using the sequence described below. Goldmann IOPs were measured last so that the subjects would experience Keeler measurements without corneal anesthesia. Successful measurements were made on all eyes. In no case was it necessary to use the Keeler Subflux option. The Airpulse+ feature was automatically engaged for five of the 452 Keeler measurements, twice because artifactually high IOPs were detected and three times because the subjects had high IOPs. No 'bad-events' were detected by the Keeler 3000.

The measurement sequence was as follows:

1. Four IOP individual readings were obtained for the subject's right eye using the Keeler 3000. The individual IOP reading as well as the mean IOP measurement produced by the Keeler were recorded. (Individual IOP readings were obtained using the Keeler 'Recall' feature.)
2. Four individual Keeler IOP readings and the mean IOP measurement were obtained for the left eye, and the results were recorded.
3. Keeler IOP measurements were repeated for the right eye.
4. Keeler IOP measurements were repeated for the left eye.

5. One drop of Fluress<sup>®</sup> (0.25% sodium fluorescein with 0.4% benoxinate HCl) was instilled into the lower cul de sac of each eye. Two minutes were allowed to elapse.
6. One Goldmann IOP measurement was made for the right eye and one was made for the left eye using standard clinical procedures.<sup>3,6</sup> The Goldmann pressure dial was masked from the examiner during measurements and was reset to a random value between measurements.
7. One Goldmann IOP measurement was repeated for the right eye and one was repeated for the left eye.

When all measurements had been completed, subjects were asked which tonometric technique they preferred. Options given were Keeler, Goldmann, Either, and Neither. No specific evaluation criteria were provided for the subjects.

## **Results**

### Correlations

A correlation matrix showing the degree to which right and left eye Keeler and Goldmann IOP measurements are related is shown in Table 3. All correlations are significantly higher than zero (t-test;  $p < 0.05$ ), and the correlations comparing Keeler to Keeler and Keeler to Goldmann measurements are significantly lower than the Goldmann to Goldmann correlations (t-test;  $p < 0.05$ ) for both eyes.

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Insert Table 3 About Here  
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Scatter plots showing the correlations between first Keeler and first Goldmann measurements for right eyes and for data from all readings for both eyes are shown in Figures 3 and 4, respectively. Scatter plots for second measurements from the right eyes and from the first and second measurements from the left eyes were similar but are not shown. All scatter plots indicate linear relationships between Keeler and Goldmann IOP measurements.

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Insert Figures 3 and 4 About Here

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#### Comparison of Mean Keeler and Goldmann IOPs

t-tests were used to compare mean IOPs measured with the Keeler and Goldmann tonometers. Separate analyses were conducted for the right and left eyes because of possible pressure differences between the eyes. Table 4 presents mean IOPs and standard deviations for the various measurements.

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Insert Table 4 About Here

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The best overall indication of whether the Keeler tends to read too high or too low with respect to the Goldmann is provided by combining the first and second measurement data from each tonometer. For the right eye, the mean Keeler IOP is 0.43 mm Hg below the comparable Goldmann mean and for the left eye it is 0.33 mm Hg below. Both of these differences are statistically significant (t-test;  $p < 0.05$ ), but neither is clinically significant.

A possible reason for the Keeler versus Goldmann differences is that mean IOPs for the second Keeler measurements are lower than the means for the first measurements, especially for the right eye data. The cause of this is unknown, but Vernon reported a similar pattern for IOPs recorded with the Pulsair 2000.<sup>6</sup>

#### Difference Measurements

Even though mean IOPs measured by the Keeler and Goldmann tonometers are similar to each other, it is possible for the Keeler to read too high in one part of the IOP range and too low in another. Mean deviations of Keeler IOPs from corresponding Goldmann values were determined on an IOP-by-IOP basis. To accomplish this, Goldmann IOPs were grouped in 1.0 mm Hg increments and the mean differences of the corresponding Keeler IOPs were calculated. Results are shown in Figure 5 (upper portion) along with the number of eyes/measurements corresponding to each Goldmann IOP (lower portion). Caution must be used when interpreting differences for which only a few cases contributed to the difference calculation, e.g., IOPs below 10 mm Hg and above 24 mm Hg.

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Insert Figure 5 About Here  
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Similar to results for the Pulsair 2000 obtained in a previous study,<sup>2</sup> Figure 5 suggests that there is a tendency for the 3000 to read slightly higher than the Goldmann for pressures up to 15 mm Hg and slightly lower for pressures above 15 mm Hg. To put this effect into perspective, a straight line was fit to the data for Goldmann IOPs between



10 and 24 mm Hg. This range was selected because there were at least thirteen eyes represented for each Goldmann pressure.

The equation for the line is:

Difference between Goldmann and Keeler readings = 1.2 mm Hg - 0.098 \*  
Goldmann IOP

Using this equation and extrapolating to Goldmann pressures of 7.0 and 30.0 mm Hg (the range of pressures measured by the 3000 in primary operating mode), the Keeler readings would be 7.5 mm Hg when the Goldmann IOP was 7.0 and 28.3 mm Hg when the Goldmann IOP was 30.0 mm Hg.

#### Individual Cases in Which Clinically Significant Differences Were Found Between Goldmann and Keeler IOPs

Overall analyses can be useful, but it is important to consider how often consecutive Keeler and Goldmann measurements differed by a clinically significant amount. Although no universally agreed upon definition of clinically significant differences between consecutive IOP measurements exists, a difference of 3.0 mm might be considered justification for repeating the measurements.

Differences were calculated between comparable right and left eye Keeler and Goldmann IOP measurements. (Table 5) Differences of 3.0 to 5.0 mm Hg between first and second measurements made with the Keeler occurred much more frequently than did 3.0 to 5.0 mm Hg differences between first and second Goldmann measurements.

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Insert Table 5 About Here  
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To further investigate large differences in measurements between first and second Keeler IOPs for the same eyes, the 6 eyes for which there was a difference of 5.0 mm Hg or more were considered. The four individual IOP readings and the resulting mean IOP measurements are shown on Table 6. For three eyes, a single outlier IOP reading seems to account for the differences; for the other three eyes, there is no apparent cause.

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Insert Table 6 About Here

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Using a Single Keeler Reading versus the Mean of Four Readings to Determine IOP

The Pulsair 3000 averages four individual IOP readings to produce its IOP measurement for the eye. However, sometimes when working with children or uncooperative subjects, only a single reading can be obtained. The clinician must then consider how well this single reading represents the Keeler-recommended mean of four readings.

Table 7 shows correlation coefficients relating the first IOP reading in each series to the mean of all four readings (i.e., the IOP measurement for the eye). Coefficients are relatively high indicating that there is good overall agreement between the first IOP reading and the mean of all four readings.

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Insert Table 7 About Here

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Figure 6 shows a histogram of differences between the first reading in the series and the four-reading mean for all eyes. Seventy-nine percent

of the first readings fell within plus or minus 2.0 mm Hg of the mean, and 96.5% of first readings were within plus or minus 4.0 mm Hg.

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Insert Figure 6 About Here

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Although Keeler does not recommend using single readings, they can provide reasonably valid indications of IOP. Caution is warranted, however, because for one eye the initial Keeler reading differed by 9.0 mm Hg from the mean of four IOPs.

#### Effects of Repeated Air-Puffs on IOP Readings

To evaluate the possibility that making four readings to obtain the mean Keeler IOP affects the IOP, perhaps by forcing fluid out of the eye and lowering the IOP, overall means of the first, second, third, and fourth individual IOP readings were calculated. These means were then compared using a repeated measures analysis of variance (ANOVA). No significant differences were found between the means ( $p > 0.05$ ). Therefore, up to four repeated puffs do not affect the IOP.

#### Tonometer Preference

At the conclusion of all measurements, subjects were asked which type of tonometer they preferred. No specific criteria were given for this choice; subjects were simply asked to evaluate the overall tonometry experience. Responses are shown on Table 8. The majority of subjects who indicated a preference chose the Keeler tonometer.

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Insert Table 8 About Here

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## Discussion

The current standard of optometric care requires assessment of glaucoma risk factors including the measurement of IOP. As optometrists consider acquiring a non-contact tonometer such as the Keeler, questions arise about whether the purchase is justifiable. Do the advantages of a Pulsair 3000 justify the approximately ten-fold cost difference between it and a Goldmann tonometer, and can IOP readings from the Pulsair be trusted?

Perhaps the greatest advantages of non-contact tonometers are that they do not require the use of pharmaceutical agents and do not make physical contact with the cornea. This means that they can be used cost-effectively by technicians in high volume practices.

A further advantage of non-contact tonometry is that probes do not need to be cleaned and disinfected. Cleaning and disinfecting seem like minor inconveniences because most pathogens are readily killed by commonly used alcohol, peroxide, or chlorine solutions, but if probes are not disinfected between right and left eye measurements, contaminants can be transferred. In addition, if prions such as those causing bovine spongiform encephalopathy and/or variant Creutzfeldt-Jakob disease exist in tears and adhere to probes, they can be transferred from patient to patient because they are not easily rendered non-pathogenic by alcohol, peroxide, or chlorine. Reuse of trial contact lenses is already a concern in England because of prion transfer fears.<sup>7</sup>

Some have even recommended that Goldmann IOP measurements for patients with any type of dementia be taken only with a disposable probe or with a cover on the probe.<sup>8,9</sup> To maintain perspective, however,

it has also been suggested that air-puff tonometers can cause microaerosolization of tears<sup>10</sup> and scatter components back to the examiner.

With respect to the Pulsair 3000 itself, the ability to bring the hand-piece to the patient rather than having to bring the patient to the tonometer offers significant advantages, especially for children. In many pediatric clinics, the Pulsair 3000 is the tonometer of choice because children tolerate the "kiss" air-puff better than they tolerate the stinging drops, blue light, and sensation of the Goldmann probe as it brushes their lashes. In this project, even the majority of adults who had a preference chose the Keeler over the Goldmann. (Table 8)

If a particular practice situation justifies the purchase of a Pulsair 3000, the next question is whether the measurements it produces are valid indicators of IOP. To answer this question, it is necessary to have a true indicator of pressure against which to compare Keeler data. In a laboratory, this would involve inserting a probe into the eye and using a mercury manometer, but for most human subjects this is not practical so Goldmann IOPs are commonly taken to indicate true IOPs. However, this means that any tonometer giving values different from Goldmann measurements would be judged as faulty even if its measurements were more accurate than Goldmann values.

Many factors such as lid pressure, corneal shape, tearing, ocular rigidity, breath holding, and the ocular pulse can affect Goldmann<sup>11-13</sup> (as well as Keeler) measurements, so care must be taken in assuming that the Keeler is "wrong" any time its readings differ from Goldmann IOPs. Although many potential sources of error, such as ocular rigidity, are not

factors in this study because measurements were made on the same eyes with each instrument, others such as the ocular pulse could be.

When Keeler and Goldmann IOP measurements are compared, it is important to remember that the period over which measurements are made differs dramatically. Goldmann IOPs are determined with the probe on the eye for several seconds or more. Often an ocular pulse is detected that causes the Goldmann rings to pulsate slightly. In practice, the IOP reading is made by adjusting the applanating force to cause the inside edges of the rings to just touch at their closest approximation; this biases the Goldmann measurements toward the lowest phase of the ocular pulse wave.

Non-contact tonometers measure IOPs with very brief puffs that are not synchronized with the ocular pulse. As a result, most air-puff tonometers average a series of individual measurements to determine the patient's IOP. Although unlikely, it is possible for each of the individual measurements to catch the ocular pulse, blink, or respiration induced pressure change at a low (or high) point and thus produce an IOP below (or above) the corresponding Goldmann value. This would reduce the correlation between Keeler and Goldmann IOPs.

In this project, correlations between consecutive Goldmann IOPs were extremely high. Correlations between consecutive Keeler IOPs and between Keeler IOPs and Goldmann IOPs were statistically lower but still quite good. (Table 3) The reasons that Keeler IOPs did not correlate as highly as Goldmann IOPs are not known but might be associated with ocular pulse waves or other physical effects such as variations in lid tension.

There were statistically significant differences between mean IOPs measured by the Keeler and Goldmann tonometers, but the differences were not clinically significant over the range of IOPs measured in this study. However, there was a tendency for Keeler IOPs to be slightly higher than Goldmann values for IOPs up to about 15 mm Hg and slightly lower for IOPs of more than 15 mm Hg. When this difference was mathematically extrapolated linearly upward to a Goldmann IOP of 30.0 mm Hg, the Keeler was predicted to read 1.7 mm Hg (6%) too low.

Of some concern is the number of individual eyes for which Goldmann and Keeler IOPs differed by clinically significant amounts. Table 5 shows that for about 20% of the comparisons between consecutive Keeler measurements or between Keeler and Goldmann measurements there was a difference of between 3.0 and 5.0 mm Hg.

Of greater concern are the six eyes for which Keeler IOP measurements differed by 5.0 to 8.0 mm Hg and the one eye for which there was a difference of 10 mm Hg between consecutive Keeler measurements. Individual IOP readings for the first measurement set from this eye were 20, 20, 38, and 29, giving a mean of 27 mm Hg. The second set of readings was 18, 15, 19, and 15, giving a mean of 17 mm Hg. Clearly, there is an outlier value of 38 in the first set of IOPs. If the 38 were eliminated, the mean of the first IOPs would become 23 mm Hg, only 5.0 mm Hg from the mean of the second IOPs.

Perhaps it would be possible for the Pulsair to monitor the individual IOP measurements as they are obtained and flag the operator when an outlier is detected, even if it does not trigger the Airpulse+ mode. For two of the three eyes represented on Table 6, the outlier values would not have engaged the Airpulse+ mode and the operator would not have



been warned that an artifactually high (or low) reading was included in the IOP average. To maintain perspective, however, it should be noted that apparent outliers occurred in only a very small number (less than 2%) of the 452 Keeler IOPs measured in this study.

In summary, the Keeler Pulsair 3000 is a clinically useful device for circumstances in which it is inconvenient or impossible to perform Goldmann tonometry. Its major advantages are pediatric and adult patient acceptance, ease of technician use, and lack of the need for pharmaceutical agents or corneal contact. Its IOP values correspond reasonably well to Goldmann values in a high proportion of eyes, but occasional outliers (possibly accurate measurements of brief IOP fluctuations) make it necessary to review individual IOP readings before accepting the average IOP measurement.

Its relative portability, ease of use, and other advantages make the Keeler Pulsair 3000 an ideal screening device, but doctors following patients for whom IOP changes of a millimeter or two measurements are critical will probably still use the "gold standard" Goldmann tonometer. Unfortunately, this choice will often be based on tradition and on the perceived accuracy of the Goldmann, which is sometimes over-estimated.



### **Acknowledgements**

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## **Foot Notes**

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- b. Personal communication. Dawn Kulp, Keeler Instruments. April 2001.

Table 1. Specifications for the Keeler Pulsair 3000.

<u>Item</u>	<u>Specification</u>
Console	Dimensions 14 x 12 x 8 inches; Weight 16 pounds
Hand-piece	10.5 x 4.5 x 1.5 inches; Weight 2 pounds
Umbilical cord length	6.5 feet
Calibrated range of IOPs	7 to 50 mm Hg in 1.0 mm steps (7.0 to 30.0 in primary mode; 30.0 to 50.0 mm Hg in Airpulse+ mode)
Training time recommended by Keeler to reach proficiency	One to two hours
Retail price (June 2001)	Approximately \$7,000

Table 2. Subject Characteristics

Age	Mean 47.3 years (SD = 18.1)
Gender	67% Females 33% Males
Race	47% Black 38% White 10% Hispanic 5% Other

Table 3. Pearson product-moment correlation coefficient matrix for OD and OS measurements. (n =113 measurement pairs for each cell.)

<u>Eye</u>	<u>Measure- ment</u>	<u>First Keeler</u>	<u>Second Keeler</u>	<u>First Goldmann</u>	<u>Second Goldmann</u>
OD	First Keeler	1.0			
OD	Second Keeler	0.86	1.0		
OD	First Goldmann	0.89	0.88	1.0	
OD	Second Goldmann	0.89	0.87	0.97	1.0
OS	First Keeler	1.0			
OS	Second Keeler	0.90	1.0		
OS	First Goldmann	0.91	0.89	1.0	
OS	Second Goldmann	0.92	0.90	0.98	1.0

Table 4. Means and standard deviations for IOP measurements. (All means are in mm Hg.)

<u>Measurement</u>	<u>Eye</u>	<u>Mean</u>	<u>Standard Deviation</u>
First Keeler	OD n = 113	16.8	4.3
Second Keeler	OD n = 113	15.8	4.0
First Goldmann	OD n = 113	16.9	4.1
Second Goldmann	OD n = 113	16.6	4.2
First Keeler	OS n = 113	16.2	4.0
Second Keeler	OS n = 113	16.0	4.0
First Goldmann	OS n = 113	16.5	4.0
Second Goldmann	OS n = 113	16.4	4.0
Combined First and Second Keeler	OD n = 226	16.3	4.2
Combined First and Second Goldmann	OD n = 226	16.8	4.1
Combined First and Second Keeler	OS n = 226	16.1	4.0
Combined First and Second Goldmann	OS n = 226	16.5	4.0



Table 5. Numbers and percentages of IOP measurements with differences indicated. Comparisons are between first Keeler and first Goldmann measurements, and between second Keeler and second Goldmann measurements for both eyes. (There are 226 possible cases in each cell.)

<u>Comparison</u>	<u>Number and Percentage With Difference of 3.0 to 5.0 mm Hg</u>	<u>Number and Percentage With Difference Over 5.0 to 8.0 mm Hg</u>	<u>Number and Percentage With Difference Over 8.0 mm Hg</u>
First Keeler versus Second Keeler	45 cases (20.0%)	1 case (0.4%)	1 case (0.4%)
First Keeler versus First Goldmann	34 cases (15.0%)	2 cases (0.9%)	0 cases (0.0%)
Second Keeler versus Second Goldmann	50 cases (22.1%)	3 cases (1.3%)	0 cases (0.0%)
First Goldmann versus Second Goldmann	5 cases (2.2%)	1 case (0.4%)	0 cases (0.0%)

Table 6. Individual readings and mean IOP measurements from the 6 cases in which there was a difference of 5.0 mm Hg or more between consecutive Keeler measurements. IOPs 1 though 4 represent individual readings. Apparent outlier readings are bolded and underlined. (All IOPs are expressed in mm Hg.)

First Set of Readings					Second Set of Readings					
IOP 1	IOP 2	IOP 3	IOP 4	Mean First IOP Set	IOP 1	IOP 2	IOP 3	IOP 4	Mean Next IOP Set	Difference
8	11	9	8	9	10	13	<b><u>26</u></b>	19	17	-8
16	19	21	24	20	20	29	22	28	25	-5
14	15	12	12	13	13	<b><u>26</u></b>	13	19	18	-5
21	23	25	28	24	14	19	22	20	19	5
27	28	26	30	28	22	21	24	24	23	5
20	20	<b><u>38</u></b>	29	27	18	15	19	15	17	10

Table 7. Correlations between first Keeler reading and the mean of four Keeler readings (n=452).

<u>Comparison</u>	<u>Correlation Coefficient</u>
First Measurement series for Right Eye	0.88
Second Measurement series for Right Eye	0.89
First Measurement series for Left Eye	0.89
Second Measurement series for Left Eye	0.85

Table 8. Preferences indicated by subjects for Keeler or Goldmann measurement procedures. (n = 113)

<u>Preference</u>	<u>Percentage</u>
Keeler	38%
Goldmann	34%
Either	26%
Neither/No response	3%

### Figure Captions

Figure 1. Measuring IOP with the Keeler Pulsair 3000.

Figure 2. Histogram of Goldmann IOPs in mm Hg for the subject population. Values plotted are first Goldmann measurements for the right and left eyes. (n = 226)

Figure 3. Scatter plot and regression line for first Keeler versus first Goldmann measurements for the subjects' right eyes. (All measurements are in mm Hg; n = 113.)

Figure 4. Scatter plot and regression line for all data. First Keeler versus first Goldmann and second Keeler versus second Goldmann comparisons for the right and left eyes are included for all subjects. (All measurements are in mm Hg; n = 452.)

Figure 5. Upper portion shows mean deviations of Keeler IOPs in mm Hg from corresponding Goldmann IOPs. The range bars enclose two standard deviations. Lower portion shows the number of subjects with each Goldmann IOP. (All IOPs in mm Hg.)

Figure 6. Histogram of differences between initial and mean Keeler IOP measurements for all subjects and all eyes. (IOPs are in mm Hg; n = 452.)

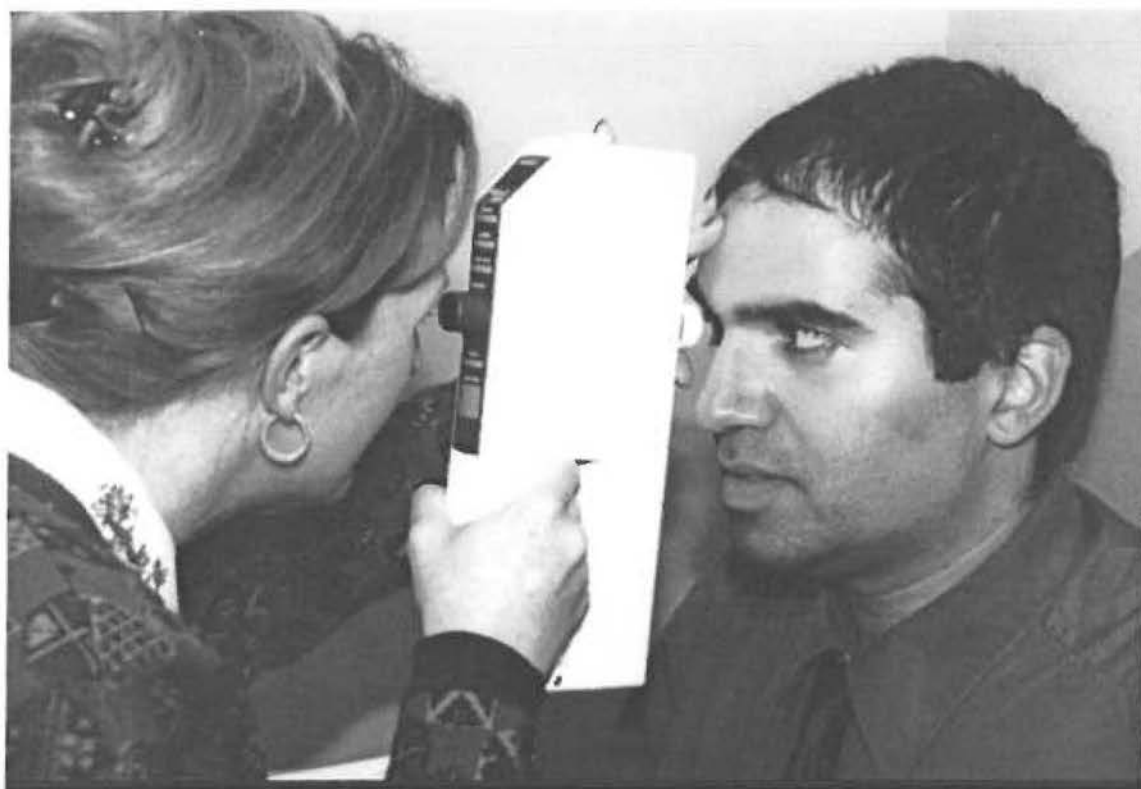


Figure 1.

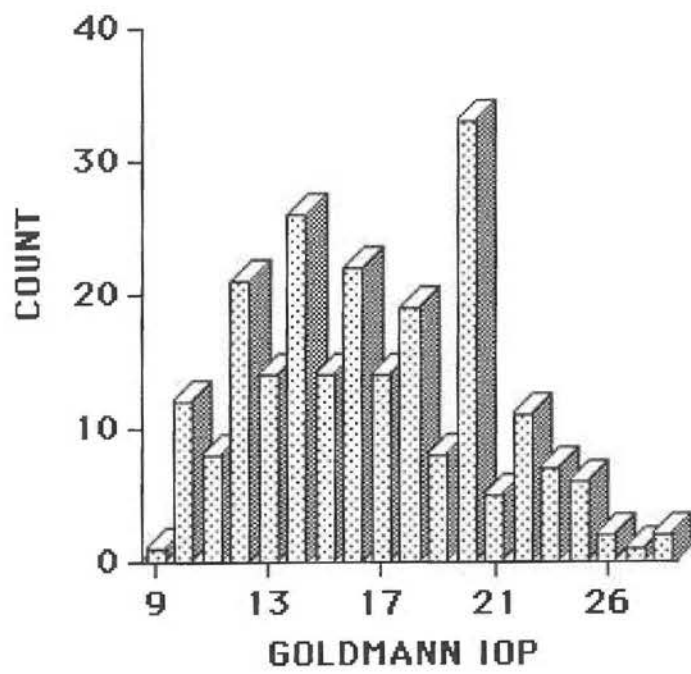


Figure 2.

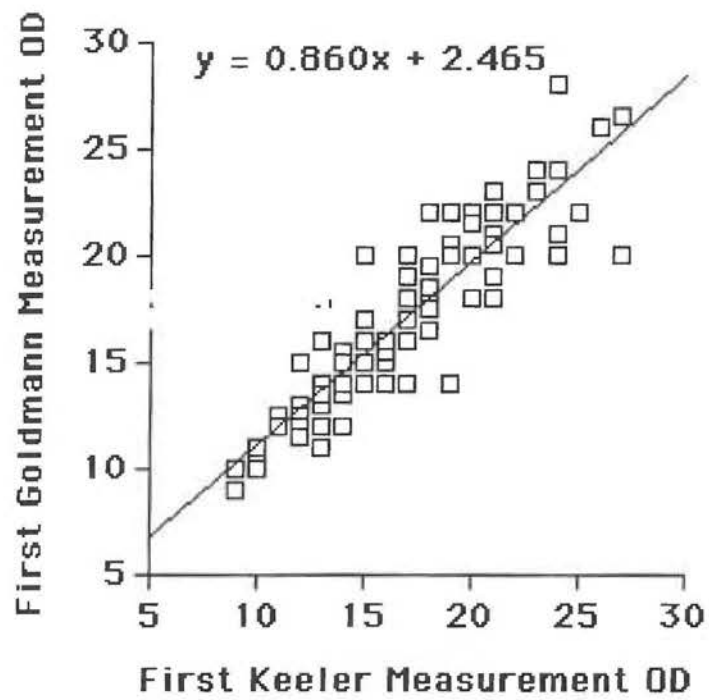


Figure 3.



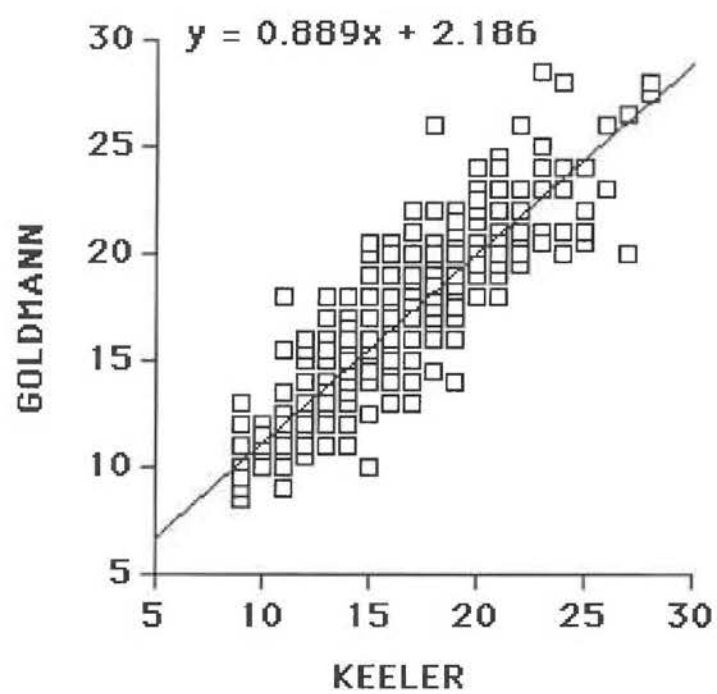


Figure 4.

MEAN GOLDMANN MINUS MEAN KEELER IOP

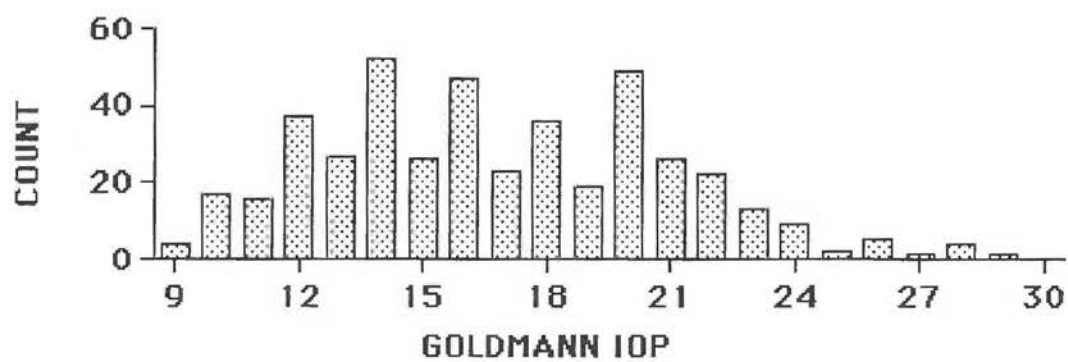
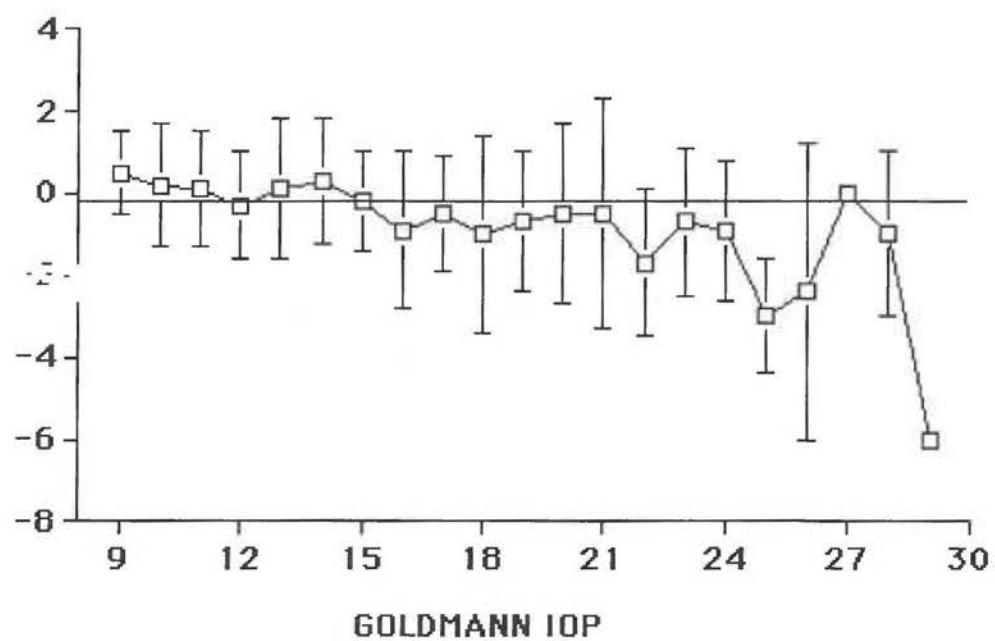


Figure 5.

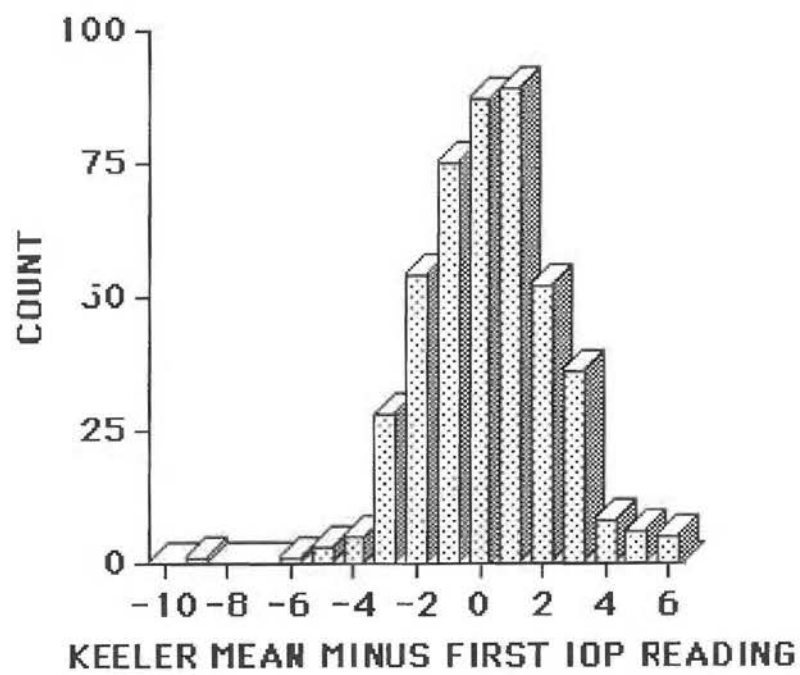


Figure 6.